Albion College Geology Guide: How to Read a Scientific Paper

Charles Darwin said, "In science the credit goes to the man who convinces the world, not to the man to whom the idea first occurs." As a scientist, one of the best ways to convince the world of your ideas is through writing. A major part of this course will involve reading and writing, both to be considered opportunities for you to become a more creative and communicative scientist.

Scientific papers are one of the most important ways that we communicate with each other.

The main purposes of a scientific paper are (1) to report new results, usually field, laboratory, and/or modeling, and (2) to relate these results to previous knowledge in the field. Most papers you are assigned will be "peer-reviewed" which means that they have been critiqued by geologists who are experts in the subject of the paper. Peer-reviews ultimately result in recommendations to 1)publish with very minor to no changes; 2) publish with major revisions which would in many cases require another peer-review; or 3) not publish. Articles that have not undergone peer-review are often referred to as "gray literature" and are considered inherently less significant regardless of content. Peer-reviewed articles are typically referred to as primary literature.

While reading primary literature is an excellent tool for promoting critical thinking about science, it can be time-consuming and frustrating. Therefore, this guide, as well as study tools used in this course, are geared to enhance your ability to read scientific papers, to comprehend what was read, and to retain the new knowledge gained.

Organization of a Scientific Paper

In most scientific journals, scientific papers follow a standard format. They are divided into several sections, and each section serves a specific purpose. We first describe the standard format, then some variations.

A paper begins with a short **Summary** or **Abstract**. Generally, it gives a brief background to the topic; the abstract/summary describes concisely the major findings of the paper; and relates these findings to the field of study.

The next section of the paper is the **Introduction**. In many journals this section is not given a title. As its name implies, this section presents the background knowledge necessary for the reader to understand why the findings of the paper are an advance on the knowledge in the field. Typically, the Introduction *describes first the accepted state of knowledge* in a specialized field; then it focuses more specifically on a particular aspect, usually describing a finding or set of findings that led directly to the work described in the paper. If the authors are testing a hypothesis, the source of that hypothesis is spelled out, findings are given with which it is consistent, and one or more predictions are given. In many papers, one or several major conclusions of the paper are presented at the end of this section for the reader to know the major answers to the questions just posed. Papers more descriptive or comparative in nature (e.g., review papers) may begin with an introduction.

The next section of most papers is the **Methods**. In some journals this section is the last section. Its purpose is to describe the materials used in the experiments and the methods by which the experiments were carried out. This description should be *detailed enough* to allow other researchers to replicate the work. In practice,

This guide is a modified and adapted from John W. Little and Roy Parker--University of Arizona (http://www.biochem.arizona.edu/classes/bioc568/ papers.htm) & Ann McNeal, Hampshire College, Amherst MA (http://helios.hampshire.edu/~apmNS/design/ RESOURCES/ HOW_READ .html)

however, the methodological descriptions are often highly compressed, and the authors often refer back to previous papers by the authors through citation.

The third section of most scientific papers is the **Results**. This section describes the experiments and the reasons they were done. Generally, the logic of the Results section follows directly from that of the Introduction. That is, the Introduction poses the questions addressed in the early part of Results. Beyond this point, the organization of Results differs from one paper to another. In some papers, the results are presented *without extensive discussion or interpretation*, which is reserved for the following section (the Discussion). This is appropriate when the data in the early parts do not need to be interpreted extensively to understand why the later studies were done. In other papers, results are given, and then they are interpreted, perhaps taken together with other findings not in the paper, so as to give the logical basis for later studies.

The fourth section is the **Discussion**. This section serves several purposes. First, the data in the paper are interpreted; that is, they are analyzed to explain what the authors believe the data show. Any limitations to the interpretations should be acknowledged, and *facts should clearly be separated from speculation*. Second, the findings of the paper are related to other findings in the field. This serves to show how the findings contribute to knowledge, or correct the errors of previous work. As stated, some of these logical arguments are often found in the Results when it is necessary to clarify why later experiments were carried out. Although you might argue that in this case the discussion material should be presented in the Introduction, more often you cannot grasp its significance until the first part of Results is given. In most scientific journals, the above format is followed. Occasionally, the Results and Discussion are combined, into one section titled **Results and Discussion** because the data need extensive discussion to allow the reader to follow the train of logic developed in the course of the research.

Finally, papers usually have a short **Acknowledgements** section, in which various contributions of other workers are recognized, followed by a **Reference** list giving references to papers and other works cited in the text. Rarely do papers have appendices.

Papers also contain several **Figures** and **Tables**, which represent the data described in the paper. The figures and tables have legends to give details of the particular experiment or experiments shown. Typically, if a procedure is used only once in a paper, these details are described in Methods, and a Figure or Table legend will refer back to that description. If a procedure is used repeatedly, however, a general description is given in Methods, and the details for a particular experiment are given in a legend.

Variations on the Organization of a Scientific Paper

The formats for two widely-read journals, *Science* and *Nature*, differ markedly from the above outline. These journals reach a wide audience, and many authors wish to publish in them; accordingly, the space limitations on the papers are severe, and the prose is usually highly compressed. In both journals, there are no discrete sections, except for a short abstract and a reference list. In *Science*, the abstract is self-contained; in *Nature*, the abstract also serves as a brief introduction to the paper. Experimental details are usually given either in endnotes (for *Science*) or Figure and Table legends and a short Methods section (in *Nature*). Authors often try to circumvent length limitations by putting as much material as possible in these places. In addition, an increasingly common practice is to put a substantial fraction of the "less-important material," and much of the methodology, into Supplemental Data that can be accessed online.

Many other journals also have length limitations, which similarly lead to a need for conciseness. For example, the *Proceedings of the National Academy of Sciences* (*PNAS*) has a 6-page limit; *Geology* has a 4-page limit and a short word limit in the abstract; so on. In response to the pressure to edit and make a paper concise (and to get their manuscripts into these aforementioned journals…), many authors choose to condense or, more typically, omit the logical connections that would make the flow of the paper easy. In addition, much of the background that would make the paper accessible to a wider audience is condensed or omitted, so that the less-informed reader has to consult a review article or previous papers to make sense of what the issues are and why they are important. Finally, again, authors often circumvent page limitations by putting crucial details into the Figure and Table legends.

Reading a Scientific Paper

Reading research papers ("primary literature") is partly a matter of experience and skill, and partly learning the specific vocabulary of a field. First of all, DON'T PANIC! If you approach it step by step, even an impossible-looking paper can be understood.

Step 1. Skim. Skim the paper quickly, noting basics like headings, figures and the like. Look at the pictures, figures, and tables. This takes just a few minutes. You're not trying to understand it yet, but just to get an overview. Although it is tempting to read the paper straight through as you would do with most text, it is more efficient to organize the way you read. Generally, you first read the Abstract in order to understand the major points of the work. The extent of background assumed by different authors, and allowed by the journal, also varies as just discussed.

Step 2. Read through once, starting with the title and abstract. Go through the paper word by word and line by line, underlining or highlighting **every word and phrase you don't understand**. Don't worry if there are a lot of underlinings; you're still not trying to make sense of the article. Formulate questions about things that are not understood or clear to you.

Don't just write, "Huh?"

With vocabulary and concept questions, depending upon the kind of question each is, you can:

a. **Look up simple words and phrases**. Often the question is simply vocabulary. Your **ordinary shelf dictionary** is **not** a good source, because the definitions may not be precise enough or may not reflect the way in which scientists use a word.
b. **Get an understanding from the context in which it is used.** Often words that are used to describe the procedures used in an experiment can be understood from the context, and may be very specific to the paper you are reading. Of course, you should be careful when deciding that you understand a word from its context, because it might not mean what you think.
c. **Flag this phrase as belonging to one of the major concepts of the paper**--it's bigger than a vocabulary question.

Step 3. Comprehension, section by section. Try to deal with all the words and phrases, although a few technical terms in the Methods section might remain. Now go back and read the whole paper, section by section, for comprehension.

This guide is a modified and adapted from John W. Little and Roy Parker--University of Arizona (http://www.biochem.arizona.edu/classes/bioc568/ papers.htm) & Ann McNeal, Hampshire College, Amherst MA (http://helios.hampshire.edu/~apmNS/design/ RESOURCES/ HOW_READ .html)

In the **Introduction**, note how the context is set. What larger question is this a part of? The author should summarize and comment on previous research, and you should distinguish between previous research and the actual current study. All research is directed (or should be) by hypotheses. What is the hypothesis of the paper and the ways this will be tested? Are there alternative hypotheses?

In the **Methods**, try to get a clear picture of what was done at each step. What was actually measured? It is a good idea to make an outline and/or sketch of the procedures and instruments. Keep notes of your questions; some of them may be simply technical, but others may point to more fundamental considerations that you will use for reflection and criticism below. Were any assumptions (explicit or implicit) made? Do you agree with the assumptions?

In **Results,** look carefully at the figures and tables, as they are the heart of most papers. A scientist will often read the figures and tables before deciding whether it is worthwhile to read the rest of the article! What does it mean to "understand" a figure? You understand a figure when you can redraw it and explain it in words.

The **Discussion** contains the conclusions that the author would like to draw from the data. In some papers, this section has a lot of interpretation and is very important. In any case, this is usually where the author should reflect on the work and its meaning in relation to other findings and to the field in general.

<u>**Step 4.**</u> **Reflection and criticism.** After you understand the article and can summarize it, then you can return to broader questions and draw your own conclusions. It is very useful to keep track of your questions as you go along, returning to see whether they have been answered. Often, the simple questions may contain the seeds of very deep thoughts about the work. Below are some guidelines and strategies for reflecting on the paper – beyond the “This paper sucks” or “I liked this paper” conclusions.

Evaluating a Paper

Too often, students resort to critiquing a paper before they truly understand the merit of the paper. In this class, I do not assign papers for critique, but instead for you to learn something from them – be it a new concept, a new method – as well as to reiterate course content. So, in reading a paper, refrain from saying to yourself, “I like this paper” or “I don’t like this paper.” Moreover, in class discussions, you should avoid saying these sentences – I don’t care if you ‘liked the paper’. I want to know what it was that you learned from the paper.

Additionally, in many cases, the papers that you are reading in this class, as well as most likely in any of your 4000- or higher courses, are the result of months to years worth of work. Not only have the authors and co-authors struggled over the best way to say something, but editors (both for content and for grammar) have corrected and modified the text. What you are reading is usually the most eloquent way of presenting an experiment, explaining data, and describing the novel aspects of the research.

So, in order to evaluate a paper, the following questions should guide you:

What questions are addressed in the paper?

Be aware that research can be of different types:

Type of research	Question asked:
Descriptive	What is there? What do we see?
Comparative	How does it compare to other organisms? Are our findings general?
Analytical	How does it work? What is the mechanism?

Descriptive research often takes place in the early stages of our understanding of a system. We can't formulate hypotheses about how a system works, or what its interconnections are, until we know what is there. **Comparative** research often takes place when we are asking how general a finding is. Is it specific to field site, or is it broadly applicable? A typical comparative approach would be comparing the tectonic setting of one collision belt with another. **Analytical** research generally takes place when we know enough to begin formulating hypotheses about how a system works, how the parts are interconnected, and what the causal connections are. A typical analytical approach would be to devise two (or more) alternative hypotheses about how a system operates. These hypotheses would all be consistent with current knowledge about the system. Ideally, the approach would devise a set of experiments to distinguish among these hypotheses.

Of course, many papers combine these approaches. Being aware that not all papers have the same approach can orient you towards recognizing the major questions that a paper addresses.

In a well-written paper, the Introduction generally goes from the general to the specific, eventually framing a question or set of questions. This is a good starting place. In addition, the results of experiments usually raise additional questions, which the authors may attempt to answer. These questions usually become evident only in the Results section.

What are the main conclusions of the paper?

This question can often be answered in a preliminary way by studying the abstract of the paper. Here the authors highlight what they think are the key points. This is not enough, because abstracts often have severe space constraints, but it can serve as a starting point. Still, you need to read the paper with this question in mind.

What evidence supports those conclusions?

Generally, you can get a pretty good idea about this from the Results section. The description of the findings points to the relevant tables and figures. This is easiest when there is one primary study to support each point. However, it is often the case that several different studies or approaches combine to support a particular conclusion. For example, the first study might have several possible interpretations, and the later experiments are designed to distinguish among these different interpretations (or alternative hypotheses).

In the ideal case, the Discussion begins with a section of the form "Three lines of evidence provide support for the conclusion that... First, ...Second,... etc." However, difficulties can arise when the paper is poorly written. The authors often do not present a concise summary of this type, leaving you to make it yourself. A skeptic might argue that in such cases the logical structure of the *argument is weak and is omitted on purpose*! In any case, you need to be sure that you understand the relationship between the data and the conclusions.

Do the data actually *support* the conclusions?

In this course, I will not give you papers in which there are questions remaining as to the validity of the work. But, one major advantage to answering this question is to help you to evaluate whether the conclusion is sound. If we assume for the moment that the data are believable, it still might be the case that the data do not actually support the conclusion the authors wish to reach.

There are at least two different ways this can happen:

- The logical connection between the data and the interpretation is not sound, or
- There might be other interpretations that might be consistent with the data, or
- The authors poorly designed the experiments to test their hypotheses, or
- The hypotheses were not testable,
- etc., the list can go on….

One important aspect to look for is whether the authors take multiple approaches to answering a question. Do they have multiple lines of evidence, from different directions, supporting their conclusions? If there is only one line of evidence, it is more likely that it could be interpreted in a different way; multiple approaches make the argument more persuasive. In *Science* and *Nature*, and even in *Geology*, multiple approaches may have been taken, but in the interest of time and space, they aren't described in the papers. Be aware that in these more coveted journals, a research paper may have been published for its *sexy* implications, but not for sound research approaches. Another thing to look for is implicit or hidden assumptions used by the authors in interpreting data. This can be hard, unless you understand the field thoroughly.

What is the quality of that evidence?

This is the hardest question to answer, for novices and experts alike. At the same time, it is one of the most important skills to learn as a young scientist. It involves a **major reorientation** and a transformation (like a caterpillar to a butterfly) from being a relatively passive consumer of information and ideas (caterpillar just eating the leaves in front of him) to an active producer and critical evaluator of them (a butterfly that can get from one plant to another, picking and choosing what it wants and evaluating the taste of one flower from another…). You should be aware the interpretation and criticism are completely different goals.

While I don't care whether you 'like' the paper or not, being able to develop your abilities to evaluate evidence is one of the hardest and most important aspects of learning to be a critical scientist and reader. This is typically where people fall into the trap of critiquing a paper solely to critique it. Therefore, answering this question is not easy and takes years to master. Beginning scientists often wonder, "*Who am I to question these authorities? After all the paper was published in* Science*, so the authors must have a high standing, and the work must have received a critical review by experts.*"

How can you evaluate the evidence?

First, you need to understand the **methods** used in the experiments, from a basic principles approach and not necessarily from a hands-on approach (you don't have to have done a procedure to understand the importance of it or the implications – positive and negative- of that procedure). Often methods are described poorly or not at all. The details are often missing, but more importantly, the authors usually assume that the reader has a general knowledge of common methods in the field. If you lack this knowledge, you have to make the extra effort to inform yourself about the basic methodology before you can evaluate the data. In the case of this course, you are learning the basics to understand the subject of the papers. Knowledge will come in due time. Don't worry too much about methods. You should also be aware of the **limitations** of the methodology. Every method has limitations, and if the experiments are not done correctly they can't be interpreted.

Second, you need to distinguish between what the actual data (figures, tables, text) show and what the authors **say** they show. The latter is really an *interpretation* on the authors' part, though it is generally not stated to be an interpretation. Papers usually state something like "the data in Fig. x show that ...". This is the authors' interpretation of the data. Do you interpret it the same way? You need to look carefully at the data to ensure that they really do show what the authors say they do. You can only do this effectively if you understand the methods and their limitations.

Third, you should ask if the proper controls are present. Controls tell us that nature is behaving the way we expect it to under the conditions of the experiment. If the controls are missing, it is harder to be confident that the results really show what is happening in the experiment. You should try to develop the habit of asking "where are the controls?" and looking for them.

Why are the conclusions important?

Do the conclusions make a significant advance in our knowledge? Do they lead to new insights, or even new research directions? Again, answering these questions requires that you understand the subject of the paper – and to integrate the subject of one paper into the content knowledge from other papers that you read. In the end, at the end of this semester, you will be able to establish the important areas of research in geology, and how new research fits into the older research.

Difficulties in Reading a Paper

Several difficulties confront the reader, particularly one who is **not** familiar with the field. Since Geology is a interdisciplinary field, one of the difficulties in reading the literature is the vocabulary. Investing a Geology dictionary will help. Asking each other for help will also help.

As discussed above, it may be necessary to bring yourself up to speed before beginning a paper, no matter how well written it is. Be aware, however, that although some problems may lie in the reader, many are the fault of the writer.

While there are many people who have read a scientific paper in order for it to be published, bad writing is possible and there are several consequences of bad writing for the reader (especially one not familiar with the field). First, the logical connections are often left out. Instead of saying why an experiment was done, or what ideas were being tested, the experiment is simply described. Second, papers are often cluttered with a great

deal of jargon. Third, the authors often do not provide a clear road-map through the paper; side issues and fine points are given equal air time with the main logical thread, and the reader loses this thread. In better writing, these side issues are relegated to Figure legends or Methods or clearly identified as side issues, so as not to distract the reader.

Another major difficulty arises when the reader seeks to understand just what the study was. All too often, authors refer back to previous papers; these refer in turn to previous papers in a loooooong chain. Often that chain ends in a paper that describes several methods, and it is unclear which was used; or the chain ends in a journal with severe space limitations, and the description is so compressed as to be unclear. More often, the descriptions are simply not well-written, so that it is ambiguous what was done.

Other difficulties arise when the authors are uncritical about their experiments; if they firmly believe a particular model, they may not be open-minded about other possibilities. These may not be tested experimentally, and may even go unmentioned in the Discussion. Still another, related problem is that *many authors do not clearly distinguish between fact and speculation*, especially in the Discussion. This makes it difficult for the reader to know how well-established are the "facts" under discussion.

One final problem arises from the sociology of science. Many authors are ambitious and wish to publish in *trendy* journals. As a consequence, they overstate the importance of their findings, or put a speculation into the title in a way that makes it sound like a well-established finding. Another example of this approach is the "Assertive Sentence Title", which presents a major conclusion of the paper as a declarative sentence. This trend is becoming prevalent. It's not so bad when the assertive sentence is well-documented, but all too often the assertive sentence is nothing more than a speculation, and the hasty reader may well conclude that the issue is settled when it isn't.

These last factors represent the public relations side of a competitive field. This behavior is understandable, if not praiseworthy. But when the authors mislead the reader as to what is firmly established and what is speculation, it is hard, especially for the novice, to know what is settled and what is not. A careful evaluation is necessary, as we will discuss in class.